What is in Our Drinking Water?

Identification of New Chemical Disinfection By-products (DBPs)

Chloroform and trichloroacetic acid, two common DBPs, in chlorinated tap water

What is a DBP?

A drinking water disinfection by-product (DBP) is formed when the chemical used for disinfecting the drinking water reacts with natural organic matter in the source water. Popular disinfectants include chlorine, ozone, chlorine dioxide, and chloramine. Source waters include rivers, lakes, streams, groundwater, and sometimes seawater. DBPs have only been known since 1974, when chloroform was identified as a DBP resulting from the chlorination of tap water. Since then, hundreds of DBPs have been identified in drinking water.

Why It's Important

Millions of people in the U.S. are exposed to these drinking water DBPs every day. While it is vitally important to disinfect drinking water, as thousands of people died from waterborne illnesses before we started disinfection practices in the early 1900s, it is also important to minimize the chemical DBPs formed. Several DBPs have been linked to cancer in laboratory animals, and as a result, the U.S. EPA has some of these DBPs regulated. However, there are many more DBPs that have still not been identified and tested for toxicity or cancer effects. Currently, less than 50% of the total organic halide that is formed in chlorinated drinking water has been identified. Total organic halide is a measure of all of the organic compounds that contain a halogen atom (chlorine, bromine, iodine), and includes DBPs such as chloroform, bromoform, and trichloroacetic acid. There is much less known about DBPs from the newer alternative disinfectants, such as ozone, chlorine dioxide, and chloramine, which are gaining in popularity in the U.S. Are these alternative disinfectants safer than chlorine? Or do they produce more harmful by-products? And, what about the unidentified chlorine DBPs that people are exposed to through their drinking water — both from drinking and showering/bathing? The objective of our research is to find out what these DBPs are — to thoroughly characterize the chemicals formed in drinking water treatment — and to ultimately minimize any harmful ones that are formed.

Our Research Approach

- Gas chromatography/mass spectrometry (GC/MS), liquid chromatography/mass spectrometry (LC/MS), and gas chromatography/infrared spectroscopy (GC/IR) techniques are used to identify the unknown by-products
- NIST and Wiley mass spectral databases are used first to identify any DBPs that happen to be present in these databases
- Because many DBPs are not in these databases, most of our work involves unconventional MS and IR techniques, as well as a great deal of scientific interpretation of the spectra
  - High resolution MS provides empirical formula information for the unknown chemical (e.g., how many carbons, hydrogens, oxygens, nitrogens, etc. are in the chemical's structure)
  - Chemical ionization MS provides molecular weight information when this is not provided in conventional electron ionization mass spectra
  - IR spectroscopy provides functional group information (e.g., whether the oxygens are due to a carboxylic acid group, a ketone, an alcohol, or an aldehyde)

Disinfection By-Products

- LC/MS is used to identify compounds that cannot be extracted from water (the highly polar, hydrophilic ones). This is a major missing gap in our knowledge about DBPs--so far, most DBPs identified have been those that are easily extracted from water
- Novel derivatization techniques are also applied to aid in the identification of highly polar DBPs

- Once DBPs are identified, ones that are predicted to have adverse health effects are studied in order to determine how they are formed (so that the treatment can be modified to ultimately minimize their presence in drinking water)

Currently

We have a major nationwide DBP occurrence study underway, where we are sampling drinking water across the U.S. (disinfected with the different disinfectants and with different water quality, including elevated levels of bromide in the source water).

Some Results

- More than 180 previously unidentified DBPs have been identified for the first time
- Ozone is tending to produce oxygen-containing DBPs, with carboxylic acids, aldehydes, ketones, and di-carbonyl compounds the most prominent
- The presence of natural bromide in the source water is resulting in a tremendous shift from chlorine-containing DBPs to bromine-containing DBPs when chlorine or chloramine is used as a disinfectant (even in combination with ozone)
- Chlorine dioxide is producing very few halogenated DBPs by itself, but when chlorine impurities are present, and natural levels of bromide or iodide are present in the source water, many bromo- and iodo-DBPs are formed
- New analytical methods have been developed (and are continuing to be developed) for the analysis of highly polar DBPs
- Collaborations have been forged with health effects researchers to study selected DBPs for potential adverse health effects

Useful Publications

1. Richardson, S.D., Thruston, Jr., A.D., Caughran, T.V., Chen, P.H., Collette, T.W., Floyd, T.L., Schenck, K.M., Lykins, Jr., B.W., Sun, G.-R., Majetich, G. “Identification of New Ozone Disinfection By-products in Drinking Water” *Environmental Science & Technology,* **1999**, *33*, 3368-3377.
2. Richardson, S.D., Thruston, Jr., A.D., Caughran, T.V., Chen, P.H., Collette, T.W., Floyd, T.L., Schenck, K.M., Lykins, Jr., B.W., Sun, G.-R., Majetich, G. “Identification of New Drinking Water Disinfection By-products Formed in the Presence of Bromide” *Environmental Science & Technology,* **1999**, *33*, 3378-3383.
3. Richardson, S.D., Thruston, Jr., A.D., Caughran, T.V., Chen, P.H., Collette, Schenck, K.M., Lykins, Jr., B.W., Rav-Acha, C., Glezer, V. “Identification of New Drinking Water Disinfection By-products from Ozone, Chlorine Dioxide, Chloramine, and Chlorine” *Water, Air, and Soil Pollution,* **2000**, *123*, 95-102.
4. Richardson, S.D., Caughran, T.V., Poiger, T., Guo, Y., Crumley, F.G. “Application of DNPH Derivatization with LC/MS to the Identification of Polar Carbonyl Disinfection By-products in Drinking Water” *Ozone: Science & Engineering,* **2000**, *22*, 653-675.

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